Notes for Responses to Questions/Concerns Raised by OFIC
Re: Protecting Cold Water Criterion of the Temperature Standard

Oregon Departments of Environmental Quality and Fish & Wildlife

Date: 6/19/2014

Questions/Assertions from Forest Industry Representatives:

1. Paired watershed studies alleged to show no correlation between temperature and salmon, steelhead, and bull trout (SSBT) population metrics.
    a. What was the temperature response in these studies?
        i. Hinkle Type-N stream-adjacent harvest (Kibler *et al* 2013):
            1. Flow increases on streams post-harvest (76-161%).
            2. Shaded due to logging slash.
            3. One stream (Fenton) had insignificant shade change (-4%), change in maximum temperature was -1.6°C.
            4. Three streams had shade decreases (-22 to -29%), change in maximum temperatures were +0.6, +0.7, +1.1°C.
            5. Pooled results for all Type-N streams indicate no significant change in maximum, mean, or minimum temperatures: No overall change.
            6. No significant temperature changes at watershed outlet (South Fork Hinkle Creek).
        ii. Hinkle Type-F stream-adjacent harvest (Arne Skaugset, *personal communication*, compiled by Terry Frueh(ODF)):
            1. Average changes of +0.4°C for stream temperature, -9.5% canopy cover on average.
            2. Temperature probes align with tributaries, not necessarily harvest units.
        iii. Alsea stream-adjacent harvest (Jeff Light, *personal communication*, compiled by Terry Frueh(ODF) & Paired Watershed Research Symposium (April 2013):
            1. Small Type-N stream: Stream temperature change was +0.5°C.
            2. Small Type-F (bottom of harvest unit): Stream temperature change was +0.7°C, -14% for shade.
            3. Small Type-F (bottom of unharvested reach downstream of harvest unit): Stream temperature change was +0.3°C.
        iv. Comparing Hinkle and Alsea Type-F stream-adjacent harvest with RipStream results (Compiled by Terry Frueh(ODF)):

Table 1. Summary data on changes in temperature, shade, and basal area for two WRC studies (Alsea and Hinkle) and RipStream.

Study (n=# of sites)	**ΔT (ºF) (n=# of sites)**	**ΔShade (%)(n=# of sites)**	**Pre-harvest total basal area (ft.^{2}/ac.) within 100 feet of stream (n=# of sites)**	**Post-harvest basal area (ft.^{2}/ac.) within 100 feet of stream (n=# of sites)**
Alsea (n=1)	+1.3 (+0.7°C)	-14	NA	37[2]
Hinkle	(n=3): +0.7[1] (+0.4°C)	(n=3): -9.5	Mainstem (n=4): 186	Mainstem (n=4): 149
			Type F tributary(n=2): 172	Type F tributary(n=2): 127
RipStream (n=18)	+1.3 (+0.7°C)	-7	Small Type F (n=4): 187	Small Type F (n=4): 87[2]
			Medium Type F (n=14): 207[2]	Medium Type F (n=14): 128

[1]Change in temperature was measured at junctions with tributaries, which does not necessarily correspond with the downstream end of a harvest unit.
[2]Total basal area excluding that of alders.

b. Did studies examine SSBT? What was general response? **[ODFW]**
   i. Hinkle did not look at SSBT, did look at resident cutthroat trout.
      1. Cutthroat: Small increases in size & total biomass (continuation of pre-harvest upward trend?).
   ii. Alsea did look at coho salmon & resident cutthroat.
      1. Coho: No response.
      2. Cutthroat: Adult biomass increased, juvenile size decreased, no response otherwise.

c. Are resident cutthroat a good proxy for SSBT? **[ODFW]**
   i. While sea-run cutthroat have similar temperature requirements as other salmonids, resident cutthroat do not have to undergo smoltification in order to survive ocean conditions. As a result, increased feeding in areas with higher temperature would not affect timing of smoltification as it does with anadromous fish (Trotter 1989).
   ii. Resident cutthroat trout have shorter lives & mature more quickly than sea-run cutthroat trout (Trotter 1989).
   iii. Irrespective of potentially different physiological needs, research indicates that cutthroat populations are found in lower abundance in secondary forest than in clear cuts or old growth (Murphy *et al* 1981).
   iv. Temperature increase of 1°C in upper extent of cutthroat habitat has been shown to not cause changes in cutthroat abundance or body condition when

understory vegetation & stream habitat was not altered by logging (DeGroot *et al* 2007).

d. What is the appropriate inference for the studies, with regard to fish?
    i. Reach level acute effects on fish population are the appropriate inference.
    ii. Short-term (ecologically speaking), local examination of population dynamics, primarily for cutthroat trout.
        1. Shows no acute damage to local cutthroat populations.
        2. Limited inference for SSBT.
        3. Limited inference for long-term local population effects.
        4. Limited inference for watershed, sub-basin, and basin level effects.
    iii. Therefore, cannot draw conclusions about SSBT at Evolutionarily Significant Unit (ESU) or sub-population level.
e. Is this assertion relevant to the purpose & construction of the temperature standard?
    i. The purpose of the standard is maintenance and restoration of natural thermal regimes. Diversity in habitat conditions enhances ecosystem resiliency.
    ii. The Protecting Cold Water (PCW) & Human Use Allowance (HUA) criteria restrict anthropogenic warming in waterbodies below & above the biologically-based numeric criteria (BBNC), respectively, & implement the purpose of the standard. The BBNC are primarily thresholds for identifying impaired waterbodies. The standard protects cold-water aquatic communities, including amphibians, macroinvertebrates, & native fish of all types.
        1. Welsh *et al* (2001) found that amphibians & coho salmon were most common (preferred) in streams with weekly average & weekly maximum temperatures below the BBNC.
            a. With MWMT <16.3 or MWAT<14.5, coho were always present.
    iii. The BBNC are set at the high end of the optimal temperature range for salmonids (US EPA 2001).
    iv. Meeting the standard preserves the capacity of waterbodies to assimilate natural fluctuations in temperature due to year-to-year climate variations & to better maintain cold-water communities in a warming climate.
    v. While the standard can be used to restrict activities that cause immediate, acute harm at the reach level, it is a regime standard designed to protect entire aquatic ecosystems from both acute & chronic anthropogenic impacts.
    vi. Therefore, the assertion ignores the larger purpose of the standard to focus on short-term, reach-level effects.

2. Alleged that there is no scientific support for the conclusion that small increases in water temperature (in reaches below the numeric criteria) are harmful to SSBT in either a localized or landscape sense, short- or long-term.
    a. We agree, to an extent, depending on how "small" is defined. That is one purpose of the 0.3°C limit on anthropogenic warming. We have a high degree of confidence that warming at or below this limit will not affect fish or cold-water communities (DEQ 2003: Temperature TAC Summary Report).

   i. Effects are on a continuum; the further we increase temperature from the natural thermal potential, the higher risk there will be for the fish.
   ii. The BBNC are set at the high end of the optimal temperature range for salmonids (US EPA 2001).
   iii. Consideration of accuracy of measurement is another reason for the 0.3°C limit. The State's policy on stream temperature is that natural thermal regimes should be protected and, where necessary, restored.
   iv. Under the Clean Water Act, existing high quality waters cannot be degraded unless it is necessary to accommodate important economical or social development in the area in which the waters are located, and BMPs are achieved for nonpoint sources.

b. Heating of headwaters reduces the extent of downstream waters at optimal growth & optimal physiological temperatures & increase the extent of downstream waters at high-risk & lethal temperatures for rearing & migration.

c. Intermittent upper reaches can provide coho habitat in residual pools during low flows & during winter high flows (Wigington *et al* 2006).
   i. Smolts overwintering in intermittent streams are larger than those overwintering in perennial streams.

d. Fish are poikilotherms, so metabolic rates & processes are regulated by the temperature of their environment (US EPA 2001).
   i. Faster metabolism results in faster growth up to the optimum growth temperature provided adequate food is available.
   ii. Faster metabolism results in energy stress when adequate food is *not* available (see McCullough 1999).
   iii. Ability to avoid predators adapted to warmer water decreases with increasing temperature. Swimming is less efficient at higher temperatures (US EPA 2001).
   iv. Invasive species often do better in warmer temperatures, tipping the competitive balance (see McCullough 1999).
   v. Changes in disease resistance with increasing temperature (McCullough 1999, US EPA 2001):
      1. Constant temperatures below 12-13°C often reduce or eliminate both infection and mortality;
      2. Temperatures above 15-16°C are often associated with high rates of infection and notable mortality;
      3. Temperatures above 18-20°C are often associated with serious rates of infection & catastrophic outbreaks of many fish diseases.
   vi. Increases in temperature flux (range) have been connected with increases in morbidity & mortality (see McCullough 1999).
      1. RipStream results show an increase in stream temperature fluxes post-harvest; this is a common effect of riparian vegetation removal.

vii. If adult fish are exposed to temperatures above 13-15.6°C during the final part of upstream migration or during holding there is a detrimental effect on the size, number, and/or fertility of eggs (US EPA 2001).

viii. Changes in behaviors can result from increases in temperature below the numeric criteria (US EPA 2001).

1. Warmer temperatures may lead to earlier out migration in salmon & reduced ocean survival (Holtby 1988).
2. Smoltification is very temperature sensitive, even to temperatures lower than the BBNC (McCullough 1999, US EPA 2001).

e. The NTR is dynamic and variable, and promotes **biological diversity** among fish populations and other native aquatic organisms.

i. The NTR includes the magnitude, frequency, duration, timing, and rate of temperature change (Olden and Naiman 2010). Landscape conversion and climate change alters the mean and *the variance* of these temperature components (Steel et al. 2012).

ii. The timing of fish life history attributes (adult migration, spawning, fry emergence, smolt migration) that are partially mediated by the NTR. This phenology reflects adaptation of salmonid populations to a "temporally-ordered" sequence of variability (Vannote and Sweeney 1980) to which fish populations have presumably adapted.

iii. Homing to natal streams promotes reproductive isolation in Pacific salmonids, and natural selective forces (including those imposed by NTR) operate on heritable phenotypic traits, resulting in distinct, *locally adapted* populations (Hillborn et al. 2003).

iv. Thus, dampening the natural thermal variability and the temporal sequence of the NTR reduces intraspecific diversity by reducing opportunities for local adaptation and genetic variation among populations or phenotypic variation within populations (Watters et al. 2003), and therefore, salmonid species diversity in Oregon.

v. Since diversity also confers stability in salmon population dynamics (production cycles), a diverse temperature regime also promotes population and meta-population (ESU) resilience. In addition, diversity in spawn timing among Pacific salmon and steelhead confers a stable food resource for other biota (Ruff et al. 2011).

f. Heat accumulation and other homogenizing effects may alter thermal heterogeneity well before changes to "average" main channel temperatures are detected (Poole and Berman 2001).

g. Thermal diversity promotes aquatic **biological productivity.**

i. If fish use temporal thermal diversity (migrating or foraging during cooler nighttime temperatures) or spatial thermal diversity (using cold-water refugia during mid-day) then impacts to the "pattern" of temperature could be as significant as changes to the mean or maximum temperature (DEQ 2003).

ii. It is not well understood how changes in temporal or spatial patterns of thermal diversity impact fish population dynamics, however it can be assumed that population dynamics are more closely linked to the dynamic spatial and temporal variability (diversity) of water temperatures and flows than to the mean of water temperatures.

iii. Fish can detect and exploit thermal heterogeneity to avoid heat stress, and meet metabolic and reproductive requirements (Berman and Quinn 1991, Hodgson and Quinn 1991, Torgersen et al. 2012).

iv. Under non-stressful temperature conditions juvenile coho that exploited thermal heterogeneity grew at substantially faster rates than did individuals that assumed other behaviors (Armstrong et al. 2013). This supports an emerging hypothesis that fish exploit thermal heterogeneity not only to survive, but thrive.

v. Variation in thermal regimes directly influence:

1. Metabolic rates, physiology and life-history traits of aquatic ectotherms (see Holtby et al. 1989 for salmonid example) and
2. Rates of important ecological processes such as nutrient cycling and productivity.
3. It also indirectly mediates biotic interactions (references in Olden and Naiman 2010).

vi. Within a watershed stream network with multiple salmonid species, those with colder thermal requirements such as ESA-listed bull trout are almost completely confined to "cold-water refuges" in higher elevation headwater streams that are spatially isolated. If these refuges become warmer, bull trout habitat availability will shrink, due to competitive disadvantage with other salmonid species in the drainage network.

vii. Thermal refuges below the species-specific BBNC buffer cool/cold water adapted species from predation by invasive warm water predators.

viii. In warm streams, thermal refuge patches provide opportunities for fish to thermoregulate (Ebersole et al. 2003). Having a spatially distributed network of reaches and segments with cooler temperatures allows a fish population to utilize a larger portion of a stream network, thereby reducing density dependent and density independent mortality.

h. Multiple stressors in the environment must be considered. By preventing or reducing temperature stress, we reduce the risks due to multiple stressors on fish populations (see Baird & Burton 2001, US EPA 2001).

i. Temperature increases, even below the numeric criteria, reduce the resistance of coho salmon to damaging effects of suspended sediment (Servizi & Martens 1991).

ii. Feeding & growth rates of native & nonnative fish which feed on juvenile salmon increase as temperature increases (EPA 2001).

iii. Cyprinid fish (e.g. redside shiners) are competitively favored over salmonids at warmer temperatures (EPA 2001).

i. Water quality (particularly summer stream temperature) was identified in the Oregon Coastal Coho Assessment & Oregon Coastal Coho Conservation Plan as the secondary bottleneck for most coastal coho ESUs.

j. Stream complexity contributes to thermal diversity.
    i. Cold groundwater (~7°C) influx & hyporheic exchange/conduction can account for apparent cooling downstream of harvest units (Story *et al* 2003). Cooling only occurred in gaining reaches.
    ii. Rather than cooling streams, hyporheic flows have a buffered temperature range (higher lows, lower highs) & are phase shifted (lagged) relative to the surface flow (water entering the hyporheic zone during the cool part of the day will likely exist during the warm part of the day & vice versa; Arrigoni *et al* 2008).
    iii. Hyporheic exchange is increased by stream complexity (Woessner 2000 & Dent *et al* 2001, cited in Story *et al* 2003 & Torgersen *et al* 2012).
    iv. Hydraulic effects of large woody debris (slowing & deflection of streamflows) create alluvial channels where there would otherwise be bedrock channels, increasing hyporheic & subsurface flow with attendant effects on temperature regimes (Montgomery *et al* 1996).
    v. Stream complexity (e.g. deflection & pool formation from boulders & large wood) increases the size & extent of cold water refugia by slowing mixing of cold water seeps with the main waterbody (Bilby 1984, cited in Torgersen *et al* 2012).

k. When there is uncertainty, DEQ must make conservative choices to ensure protection of the resource.
    i. Uncertainty due to dynamics of the system (stochasticity).
    ii. Uncertainty due to our incomplete understanding of the system.
    iii. Uncertainty due to using sample data to observe the system.

3. Alleged that increases in temperature (at levels seen in RipStream) will diminish to less than 0.3°C within 300m on average. What can we say about downstream effects (in detail)?
    a. Physics of heat gain/loss.
        i. During summer, efficiency of heat loss is much lower than that of heat gain via solar radiation.
            1. In open canopy streams, input of solar radiation typically composes about 50% – 90% of the total heat energy flux (Johnson 2004, Benyahya *et al* 2012) & is the primary driver of heat transfer related to stream temperature change (Figures 1 & 2).
        ii. Added flow (increased mass of water) dilutes heat, but most heat remains in the system (e.g. Hannah *et al* 2008).
            1. Harder to detect the effects of a *single* source as water moves farther downstream.

        2. Temperature is a measure of average thermal energy content, but DEQ also tracks thermal energy loads & fluxes (kcal) in TMDLs & other water quality programs.
    iii. On small streams, DEQ HeatSource modeling indicates long distances (1000 meters +) are required to lose heat energy via evaporation and longwave radiation.
        1. The loss is slow because these fluxes are the primary processes for loss of heat, and they represent a small proportion of the total input from increased solar radiation (Figure 1).
        2. Tributary & groundwater mixing are held constant; only effects of vegetation change are modeled.
    iv. DEQ HeatSource modeling indicates long distances (1000 meters +) are required to lose thermal energy via evaporation & longwave radiation (when flow is increased by x% to account for harvest-related flow increases).
        1. Surfleet & Skaugset (2013) found 45% increase in August flows with 13% of watershed harvested in 2005. When an additional 13% was harvested in 2009 (26% total), flows were 106% higher in the 1st year (2010) & 47% higher in the 2nd year (2011).
        2. Jones & Post (2004) looked at small PNW catchments with 100% harvest:
            a. ~50-100% increase in summer (June-Mid September) low flows 1-5 yrs post-harvest
            b. ~0-60% increase in summer low flows 6-10 yrs post-harvest
            c. ~30-50% deficits in summer low flows 24-35 yrs post-harvest
    v. HeatSource modeling on 2 RipStream sites (5556 & 7854):
        1. Agrees well with field measured responses at the end of the harvest units;
        2. Shows persistent temperature increases a kilometer or more from the end of harvest units (Figures 3 & 4);
        3. Harvest of additional downstream unit on 5556 creates greater increase at confluence with Drift Creek (Figure 5).
b. Trask Study results?
    i. Preliminary results shown in Trask presumably showed privately harvested Type-N streams did not have readily detectable effects at downstream probe.
    ii. Small headwaters (small Type-N) streams often behave differently & have small flows compared to fish-bearing reaches.
        1. There is a great deal of change in heat capacity between harvest reaches & downstream sites, due to greater flows.
    iii. The format of data presented to the GNRO is difficult to understand—need more information to have an interpretation of this data.

        1. For example, does not appear to be harvest-related temperature changes on Type-N streams in harvest units. If true, wouldn't expect changes at downstream sites.
    iv. Between Type-N harvest units & downstream probe is a RipStream study site.
        1. During pre-harvest (2006-2011) period of Trask Study, RipStream site was in post-harvest condition (harvested in 2005, post-harvest year 1 was 2006).
        2. RipStream site had challenging-to-interpret temperature behavior. 2W (control) probe had post-harvest increases & there was not much harvest in the Riparian Management Area, so unable to see any effects at 3W (treatment) probe.
        3. Does this site confound interpretation of downstream effects from headwaters harvests?
  c. Cole & Newton (2013) showed that with uncut units interspersed with harvest units, stream reaches showed overall increases in temperature trends 2 or 5 years post-harvest for 3 of 4 study reaches.
  d. If taking a non-conservative approach to the effects of a single harvest, then we must address actual landscape conditions & the effects of multiple harvests.

4. Alleged that 2% of landscape in "early years" of rotation. What is the typical range, and what can we say about that?
  a. Two questions:
    i. How are the "early years" of the rotation being defined? It appears this figure may be % harvested per year on an even-flow 50-year rotation.
        1. An appropriate thermal recovery window is 7-15 years, given the literature on temperature/shade recovery (Johnson & Jones 2000; D'Souza *et al* 2011; Rex *et al* 2012; RipStream data, *unpublished*).
        2. Ten years is a reasonable mid-range timespan (See studies above; also Sherri Johnson, *personal communication*).
    ii. What spatial scale is being considered? How does ownership vary across space?
  b. Answers:
    i. 2% harvested per year on average for a 50 year rotation. Rotation length is more often 40 years, so 2.5% of the land harvested per year on average. For a 10 year temperature recovery timespan, 25% of industrial forestlands would be in thermal recovery.
    ii. There is high variation in percent ownership of forestlands (federal, state, municipal, private nonindustrial, private industrial) by sub-basin and basin and in harvest patterns.
    iii. The average percentage of private forestland (65.1% of total land area) in the MidCoast basin in the 10-yr thermal recovery period is 17% for the time period 1985-2009. The average for all land uses combined is 10%.
        1. An additional 5% did not have tree cover before 1985 & has not grown trees subsequently.

2. Varies over time & space.
    a. In 2008, 39.9% of private forestland in the Middle Siletz River watershed was in thermal recovery.
    b. In 1996, 5.3% of private forestland in the Drift Creek watershed was in thermal recovery. [34.9% in 2008]
3. Disturbance is calculated in rolling 10-yr intervals based on change in Landsat land cover from 1985-2009 (Figure 6).
4. Disturbance includes both harvest & fire.
5. Consistent with digitized harvest units area in ODF Vantage database (Kyle Abraham, *personal communication*)

iv. Based on change in Landsat land cover from 1985-2009, the average percentage of private forestland riparian areas in the MidCoast basin (43.8% of total riparian area (within 100ft of streams)) in the 10-yr thermal recovery period is 14.1% for the time period 1994-2009.
1. The average for private industrial forestland is 15.6% (36.2% of total riparian area) & for private nonindustrial forestland is 10.2% (7.6% of total riparian area).
2. The percentage of recently+chronically disturbed riparian areas is 20.7% for private forestlands during the same time period (20.4% & 21.8% for industrial & nonindustrial, respectively).
3. The average recent disturbance for riparian areas of all land uses collectively is 8.7%. The average chronic disturbance for riparian areas of all land uses collectively is 14.0%.
4. Varies over time & space.
    a. In 2008, 36.7% of private forestland riparian area in the Middle Siletz River watershed was in thermal recovery (maximum). The minimum of 14.1% occurred in 1994 (Figures 7 & 8).
    b. In 1996, 0.2% of private forestland riparian area in the Drift Creek watershed was in thermal recovery (minimum). The maximum of 25.8% occurred in 2008 (Figures 9 & 10).
    c. In 1999, 9.7% of private forestland riparian area in the Lake Creek watershed was in thermal recovery (minimum). The maximum of 34.5% occurred in 2008 (Figures 11 & 12).

v. In ODF's landslide study, (Robison *et al* 1999) 17% of study areas were in age class 0-9.

c. Prior to Euro-American settlement, fires created a heterogeneous (patchy) landscape with variable fire severity &varying intervals between fires.

i. Fire return intervals in western Oregon range from 100-400 years. Shorter intervals typically are associated with less severity (Morrison & Swanson 1990).

ii. Agee (1990) estimates that historically an average 0.24% and 0.67% of cedar/spruce/hemlock and Douglas-fir forests, respectively, burned annually.

    iii. Cedar/spruce/hemlock average per 10 years=2.4%; Douglas-fir average per 10 years=6.7%.

d. Wimberly (2002) estimates that a median of 17% of Oregon's coastal province would be in early successional condition (<30 years since fire).
    i. These fires are not all stand replacement but vary in severity.
    ii. Using 10 years as above, Wimberly's estimate gives 5.67% of forestlands historically in thermal recovery.
    iii. Swanson *et al* (2011) document the differences between natural early succession and clearcut harvest.

e. High-severity fires leave more wood & live vegetation than clearcut harvest (see Reeves *et al* 2006). Fire return for high severity fires is typically 200 years (Wimberly 2002), compared to harvest rotation of 40 years.

f. Periodic large scale disturbances create a mosaic of riparian & aquatic habitats (Bisson *et al* 2003). Pulses of sediment & large wood are delivered by post-fire erosion, in contrast to chronic inputs.
    i. Emphasize the importance of conserving & restoring processes, not merely creating a structure or a condition.
    ii. Managing for & like a natural disturbance.

g. Fire is less common in riparian areas (higher moisture content & humidity). They often have higher fuel loads (higher productivity) & in prolonged drought become more fire-prone. Riparian fires tend to be very patchy, primarily burning fine fuels. Some studies (e.g. Tollefson *et al* 2004, Olson & Agee 2005) have found no difference between upland & riparian fire frequency, particularly when riparian vegetation is similar to upland vegetation. Streams higher up in watersheds are more likely to burn along with upland forests. (Upper riparian forests: more fire disturbance; lower riparian forests: more flood disturbance.) Conditions retard fuel drying & decrease severity. Harvesting increases fuel loads & opens up canopy, allowing faster drying of fuels. Extent & spread complicated by heterogeneity. In very dry climatic conditions, riparian corridors can act a route fire spread (wind tunnel effect). More often, riparian areas make a natural fire break. Riparian vegetation diversity & adaptations & access to water lead to faster recovery (Reeves *et al* 2006, Pettit & Naiman 2007).

h. Olson & Agee (2005) found historic fire return intervals of 4-167 years for riparian areas & 2-110 years for upland area in the mixed-severity fire regime of the Umpqua basin (not significantly different). Fire was patchy & riparian areas had a greater range of return intervals than upland slopes.
    i. Drier end of Douglas-fir/western hemlock distribution.

i. Windthrow is a common riparian disturbance type that contributes large wood to streams & creates patches of different ages. Windthrow rates are significantly higher on buffered clearcut streams compared to partial cuts or controls; however, it is a minor contributor to overall sediment loads (Rashin *et al* 2006). Loss of trees would reduce shade.

j. Conifers are uncommon in many unmanaged Coast Range riparian areas. Hardwood dominance due to competition & small-scale disturbance is common (Nierenberg & Hibbs 2000).
k. Temperature 303(d) listings & TMDLs exist across Oregon's landscape.
l. If only 2-6% of landscape were in recently harvested (≤10yrs since harvest) condition at the 6th field scale, then there are significantly reduced risks of water quality impacts & fisheries impacts (see Thompson *et al* 2006 for information on historical disturbance as a reference for forest policy/harvest).

References:

Agee, James K. 1990. The historical role of fire in Pacific Northwest forests, p. 25-38. *In* Walstad, JD, SR Radosevich, and DV Sandberg (*eds.*) Natural and Prescribed Fire in Pacific Northwest Forests. Oregon State University Press, Corvallis, Oregon. 317pp.

Arrigoni, AS, GC Poole, LAK Mertes, SJ O'Daniel, WW Woessner, and SA Thomas. 2008. Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stream channels. Water Resources Research 44: W09418, doi:10.1029/2007WR006480.

Baird, DJ & GA Burton, Jr. (eds.) 2001. Ecological Variability: Separating Natural from Anthropogenic Causes of Impairment. Pensacola, Florida , USA: SETAC Press. 307pp.

Benyahya, L, D Caissie, MG Satish, and N El-Jabi. 2012. Lon-wave radiation and heat flux estimates within a small tributary in Catamaran Brook (New Brunswick, Canada). *Hydrological Processes* **26:** 475-484.

Bilby, RE. 1984. Characteristics and frequency of cool-water areas in a western Washington stream. *Journal of Freshwater Ecology* **2:** 593-602.

Bisson, PA, BE Rieman, C Luce, PF Hessberg, DC Lee, JS Kershner, GH Reeves, and RE Gresswell. 2003. Fir and aquatic ecosystems of the western USA: current knowledge and key questions. *Forest Ecology and Management* **178:** 213-229.

Cole, E, and M Newton. 2013. Influence of streamside buffers on stream temperature response following clear-cut harvesting in western Oregon. *Canadian Journal of Forest Research* **43:** 993-1005.

DeGroot, JD, SG Hinch, and JS Richardson. 2007. Effects of logging second-growth forests on headwater populations of coastal cutthroat trout: a 6-year, multistream, before-and-after field experiment. *Transactions of the American Fisheries Society* **136:** 211-226.

Dent, CL, NB Grimm, and SG Fisher. 2001. Multiscale effects of surface-subsurface exchange on stream water nutrient concentrations. Journal of the North American Benthological Society 20: 162-181.

DEQ. 2003. Summary of the Discussion and Findings of DEQ's Technical Advisory Committee on Water Quality Criteria for Temperature. http://www.deq.state.or.us/wq/standards/docs/temperature/TACsummaryTemp2003.pdf

D'Souza, L, M Reiter, LJ Six, & RE Bilby. 2011. Response of vegetation, shade and stream temperature to debris torrents in two western Oregon watersheds. *Forest Ecology and Management* **261:** 2157-2167.

Hannah, DM, IA Malcolm, C Souslby, and AF Youngson. 2008. A comparison of forest and moorland stream microclimate, heat exchanges and thermal dynamics. *Hydrological Processes* **22:** 919-940.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (Oncorhynchus kisutch). *Canadian Journal of Fisheries and Aquatic Sciences* **45**: 502-515.

INR (Institute for Natural Resources at Oregon State University). 2009. Managing for climate change in an ecosystem dynamics framework: Recommendations from April 16, 2009 seminar. *Dynamic Ecosystem Policy Project (Oregon Department of Forestry).* http://www.oregon.gov/odf/resource_planning/docs/inr_climate_change_white_paper.pdf

Johnson, Sherri L. 2004. Factors influencing stream temperatures on small streams: substrate effects and a shading experiment. *Canadian Journal of Fisheries and Aquatic Sciences* **61:** 913-923.

Johnson, SL, and JA Jones. 2000. Stream temperature response to forest harvest and debris flows in western Cascades, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* **57(Suppl. 2):** 30-39.

Jones, JA, and DA Post. 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. *Water Resources Research* **40:** W05203, doi:10.1029/2003WR002952.

Kibler, KM, A Skaugset, LM Ganio, and MM Huso. 2013. Effect of contemporary forest harvesting practices on headwater stream temperatures: Initial response of the Hinkle Creek catchment, Pacific Northwest, USA. *Forest Ecology and Management* **310:** 680-691.

McCullough, DA. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. *United States Environmental Protection Agency Publication* EPA 910-R-99-010. 279pp.

Montgomery, DR, TB Abbe, JM Buffington, NP Peterson, KM Schmidt, and JD Stock. 1996. Distribution of bedrock and alluvial channels in forested mountain drainage basins. *Nature* **381:** 587-589.

Morrison, PH, and FJ Swanson. 1990. Fire history and pattern in a Cascade Range landscape. US Forest Service General Technical Report: PNW-GTR-254. 77pp.

Mote, Philip W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. *Northwest Science* **77:** 271-281.

Murphy, ML, C P Hawkins, and NL Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. *Trans. Am. Fish. Soc.* **110:** 469-478.

Nierenberg, TR, and DE Hibbs. 2000. A characterization of unmanaged riparian areas in the central Coast Range of western Oregon. *Forest Ecology and Management* **129:** 195-206.

Olson, DL, and JK Agee. 2005. Historical fires in Douglas-fir dominated riparian forests of the southern Cascades, Oregon. *Fire Ecology* **1:** 50-74.

Oregon Coastal Coho Conservation Plan. http://www.oregon.gov/OPSW/cohoproject/pdfs/november2007_pdfs/coho_plan.pdf

Pettit, NE, and RJ Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. *Ecosystems* **10:** 673-687.

Rashin, EB, CJ Clishe, AT Loch, and JM Bell. 2006. Effectiveness of timber harvest practices for controlling sediment related water quality impacts. *Journal of the American Water Resources Association* **42:** 1307-1327.

Reeves, GH, LE Benda, KM Burnett, PA Bisson, and JR Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. *American Fisheries Society Symposium* **17:** 334-349.

Reeves, GH, PA Bisson, BE Rieman, and LE Benda. 2006. Postfire logging in riparian areas. *Conservation Biology* **20:** 994-1004.

Rex, JF, DA Maloney, PN Krauskopf, PG Beaudry, and LJ Beaudry. 2012. Variable-retention riparian harvesting effects on riparian air and water temperature of sub-boreal headwater streams in British Columbia. *Forest Ecology and Management* **269:** 259-270.

Robison, E.G., K. Mills, J. Paul, L. Dent, and A. Skaugset. 1999. Oregon Department of Forestry Storm Impacts and Landslides of 1996: Final Report. Forest Practices Technical Report No. 4. Oregon Department of Forestry, Salem, Oregon.

Ruesch, AS, CE Torgersen, JJ Lawler, JD Olden, EE Peterson, CJ Volk, and DJ Lawrence. 2012. Projected climate-induced habitat loss for salmonids in the John Day River network, Oregon, U.S.A. *Conservation Biology* **26:** 873-882.

Servizi, JA, and DW Martens. 1991. Effect of temperature, season, and fish size on acute lethality of suspended sediments to coho salmon (*Oncorhynchus kisutch*). *Can J Fish Aquat Sci* **48:** 493-497.

Story, A, ED Moore, and JS Macdonald. 2003. Stream temperatures in two shaded reachesbelow cutblocks and logging roads: downstream cooling linked to subsurface hydrology. *Canadian Journal of Forest Research* **33:** 1383-1396.

Surfleet, CG, and AE Skaugset. 2013. The effect of timber harvest on summer low flows, Hinkle Creek, Oregon. *Western Journal of Applied Forestry* **28:** 13-21.

Swanson, ME, JF Franklin, RL Beschta, CM Crisafulli, DA DellaSala, RL Hutto, DB Lindenmayer, and FJ Swanson. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Frontiers in Ecology and the Environment* **9:** 117-125.

Thompson, JR, KN Johnson, M Lennette, TA Spies, and P Bettinger. 2006. Historical disturbance regimes as a reference for forest policy in a multiowner province: a simulation experiment. *Canadian Journal of Forestry Research* **36:** 401-417.

Tollefson, JE, FJ Swanson, and JH Cissel. 2004. Fire severity in intermittent drainages, Western Cascade Range, Oregon. *Northwest Science* **78:** 186-191.

Torgersen, CE, JL Ebersole, and DM Keenan. 2012. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. *United States Environmental Protection Agency Publication* EPA 910-C-12-001. 78pp.

Trotter, P. C. 1989. Coastal Cutthroat Trout: A Life History Compendium. *Trans. Am. Fish. Soc.* **118:** 463-473.

US EPA, Region 10. 2001. Temperature Project Technical Issue Papers. http://yosemite.epa.gov/r10/water.nsf/6cb1a1df2c49e4968825688200712cb7/5eb9e547ee9e111f88256a03005bd665!OpenDocument

Welsh, HH, GR Hodgson, and BC Harvey. 2001. Distribution of juvenile coho salmon in relation to water temperatures in tributaries of the Mattole River, California. *North American Journal of Fisheries Management* **21:** 464-470.

Wigington, PJ Jr., and others. 2006. Coho salmon dependence on intermittent streams. *Frontiers in Ecology and the Environment* **4:** 513-518.

Woessner, WW. 2000. Stream and fluvial plain ground water interactions: rescaling hydrogeologic thought. *Ground Water* **38:** 423-429.

Wimberly, MC. 2002. Spatial simulation of historical landscape patterns in coastal forests of the Pacific Northwest. *Canadian Journal of Forest Research* **32:** 1316-1328.

Notes for Responses to Questions/Concerns Raised by OFIC
Re: Protecting Cold Water Criterion of the Temperature Standard

Oregon Departments of Environmental Quality and Fish & Wildlife

Date: 6/19/2014

Questions/Assertions from Forest Industry Representatives:

1. Paired watershed studies alleged to show no correlation between temperature and salmon, steelhead, and bull trout (SSBT) population metrics.
    a. What was the temperature response in these studies?
        i. Hinkle Type-N stream-adjacent harvest (Kibler *et al* 2013):
            1. Flow increases on streams post-harvest (76-161%).
            2. Shaded due to logging slash.
            3. One stream (Fenton) had insignificant shade change (-4%), change in maximum temperature was -1.6°C.
            4. Three streams had shade decreases (-22 to -29%), change in maximum temperatures were +0.6, +0.7, +1.1°C.
            5. Pooled results for all Type-N streams indicate no significant change in maximum, mean, or minimum temperatures: No overall change.
            6. No significant temperature changes at watershed outlet (South Fork Hinkle Creek).
        ii. Hinkle Type-F stream-adjacent harvest (Arne Skaugset, *personal communication*, compiled by Terry Frueh(ODF)):
            1. Average changes of +0.4°C for stream temperature, -9.5% canopy cover on average.
            2. Temperature probes align with tributaries, not necessarily harvest units.
        iii. Alsea stream-adjacent harvest (Jeff Light, *personal communication*, compiled by Terry Frueh(ODF) & Paired Watershed Research Symposium (April 2013):
            1. Small Type-N stream: Stream temperature change was +0.5°C.
            2. Small Type-F (bottom of harvest unit): Stream temperature change was +0.7°C, -14% for shade.
            3. Small Type-F (bottom of unharvested reach downstream of harvest unit): Stream temperature change was +0.3°C.
        iv. Comparing Hinkle and Alsea Type-F stream-adjacent harvest with RipStream results (Compiled by Terry Frueh(ODF)):

Table 1. Summary data on changes in temperature, shade, and basal area for two WRC studies (Alsea and Hinkle) and RipStream.

Study (n=# of sites)	ΔT (ºF) (n=# of sites)	ΔShade (%)(n=# of sites)	Pre-harvest total basal area ($ft.^2/ac.$) within 100 feet of stream (n=# of sites)	Post-harvest basal area ($ft.^2/ac.$) within 100 feet of stream (n=# of sites)
Alsea (n=1)	+1.3 (+0.7°C)	-14	NA	37[2]
Hinkle	(n=3): +0.7[1] (+0.4°C)	(n=3): -9.5	Mainstem (n=4): 186	Mainstem (n=4): 149
			Type F tributary(n=2): 172	Type F tributary(n=2): 127
RipStream (n=18)	+1.3 (+0.7°C)	-7	Small Type F (n=4): 187	Small Type F (n=4): 87[2]
			Medium Type F (n=14): 207[2]	Medium Type F (n=14): 128

[1]Change in temperature was measured at junctions with tributaries, which does not necessarily correspond with the downstream end of a harvest unit.
[2]Total basal area excluding that of alders.

b. Did studies examine SSBT? What was general response? **[ODFW]**
    i. Hinkle did not look at SSBT, did look at resident cutthroat trout.
        1. Cutthroat: Small increases in size & total biomass (continuation of pre-harvest upward trend?).
    ii. Alsea did look at coho salmon & resident cutthroat.
        1. Coho: No response.
        2. Cutthroat: Adult biomass increased, juvenile size decreased, no response otherwise.

c. Are resident cutthroat a good proxy for SSBT? **[ODFW]**
    i. While sea-run cutthroat have similar temperature requirements as other salmonids, resident cutthroat do not have to undergo smoltification in order to survive ocean conditions. As a result, increased feeding in areas with higher temperature would not affect timing of smoltification as it does with anadromous fish (Trotter 1989).
    ii. Resident cutthroat trout have shorter lives & mature more quickly than sea-run cutthroat trout (Trotter 1989).
    iii. Irrespective of potentially different physiological needs, research indicates that cutthroat populations are found in lower abundance in secondary forest than in clear cuts or old growth (Murphy *et al* 1981).
    iv. Temperature increase of 1°C in upper extent of cutthroat habitat has been shown to not cause changes in cutthroat abundance or body condition when

understory vegetation & stream habitat was not altered by logging (DeGroot *et al* 2007).

d. What is the appropriate inference for the studies, with regard to fish?
   i. Reach level acute effects on fish population are the appropriate inference.
   ii. Short-term (ecologically speaking), local examination of population dynamics, primarily for cutthroat trout.
      1. Shows no acute damage to local cutthroat populations.
      2. Limited inference for SSBT.
      3. Limited inference for long-term local population effects.
      4. Limited inference for watershed, sub-basin, and basin level effects.
   iii. Therefore, cannot draw conclusions about SSBT at Evolutionarily Significant Unit (ESU) or sub-population level.
e. Is this assertion relevant to the purpose & construction of the temperature standard?
   i. The purpose of the standard is maintenance and restoration of natural thermal regimes. Diversity in habitat conditions enhances ecosystem resiliency.
   ii. The Protecting Cold Water (PCW) & Human Use Allowance (HUA) criteria restrict anthropogenic warming in waterbodies below & above the biologically-based numeric criteria (BBNC), respectively, & implement the purpose of the standard. The BBNC are primarily thresholds for identifying impaired waterbodies. The standard protects cold-water aquatic communities, including amphibians, macroinvertebrates, & native fish of all types.
      1. Welsh *et al* (2001) found that amphibians & coho salmon were most common (preferred) in streams with weekly average & weekly maximum temperatures below the BBNC.
         a. With MWMT <16.3 or MWAT<14.5, coho were always present.
   iii. The BBNC are set at the high end of the optimal temperature range for salmonids (US EPA 2001).
   iv. Meeting the standard preserves the capacity of waterbodies to assimilate natural fluctuations in temperature due to year-to-year climate variations & to better maintain cold-water communities in a warming climate.
   v. While the standard can be used to restrict activities that cause immediate, acute harm at the reach level, it is a regime standard designed to protect entire aquatic ecosystems from both acute & chronic anthropogenic impacts.
   vi. Therefore, the assertion ignores the larger purpose of the standard to focus on short-term, reach-level effects.

2. Alleged that there is no scientific support for the conclusion that small increases in water temperature (in reaches below the numeric criteria) are harmful to SSBT in either a localized or landscape sense, short- or long-term.
   a. We agree, to an extent, depending on how "small" is defined. That is one purpose of the 0.3°C limit on anthropogenic warming. We have a high degree of confidence that warming at or below this limit will not affect fish or cold-water communities (DEQ 2003: Temperature TAC Summary Report).

    i. Effects are on a continuum; the further we increase temperature from the natural thermal potential, the higher risk there will be for the fish.
    ii. The BBNC are set at the high end of the optimal temperature range for salmonids (US EPA 2001).
    iii. Consideration of accuracy of measurement is another reason for the 0.3°C limit. The State's policy on stream temperature is that natural thermal regimes should be protected and, where necessary, restored.
    iv. Under the Clean Water Act, existing high quality waters cannot be degraded unless it is necessary to accommodate important economical or social development in the area in which the waters are located, and BMPs are achieved for nonpoint sources.

b. Heating of headwaters reduces the extent of downstream waters at optimal growth & optimal physiological temperatures & increase the extent of downstream waters at high-risk & lethal temperatures for rearing & migration.
c. Intermittent upper reaches can provide coho habitat in residual pools during low flows & during winter high flows (Wigington *et al* 2006).
    i. Smolts overwintering in intermittent streams are larger than those overwintering in perennial streams.
d. Fish are poikilotherms, so metabolic rates & processes are regulated by the temperature of their environment (US EPA 2001).
    i. Faster metabolism results in faster growth up to the optimum growth temperature provided adequate food is available.
    ii. Faster metabolism results in energy stress when adequate food is *not* available (see McCullough 1999).
    iii. Ability to avoid predators adapted to warmer water decreases with increasing temperature. Swimming is less efficient at higher temperatures (US EPA 2001).
    iv. Invasive species often do better in warmer temperatures, tipping the competitive balance (see McCullough 1999).
    v. Changes in disease resistance with increasing temperature (McCullough 1999, US EPA 2001):
        1. Constant temperatures below 12-13°C often reduce or eliminate both infection and mortality;
        2. Temperatures above 15-16°C are often associated with high rates of infection and notable mortality;
        3. Temperatures above 18-20°C are often associated with serious rates of infection & catastrophic outbreaks of many fish diseases.
    vi. Increases in temperature flux (range) have been connected with increases in morbidity & mortality (see McCullough 1999).
        1. RipStream results show an increase in stream temperature fluxes post-harvest; this is a common effect of riparian vegetation removal.

vii. If adult fish are exposed to temperatures above 13-15.6°C during the final part of upstream migration or during holding there is a detrimental effect on the size, number, and/or fertility of eggs (US EPA 2001).

viii. Changes in behaviors can result from increases in temperature below the numeric criteria (US EPA 2001).

1. Warmer temperatures may lead to earlier out migration in salmon & reduced ocean survival (Holtby 1988).
2. Smoltification is very temperature sensitive, even to temperatures lower than the BBNC (McCullough 1999, US EPA 2001).

e. The NTR is dynamic and variable, and promotes **biological diversity** among fish populations and other native aquatic organisms.

i. The NTR includes the magnitude, frequency, duration, timing, and rate of temperature change (Olden and Naiman 2010). Landscape conversion and climate change alters the mean and *the variance* of these temperature components (Steel et al. 2012).

ii. The timing of fish life history attributes (adult migration, spawning, fry emergence, smolt migration) that are partially mediated by the NTR. This phenology reflects adaptation of salmonid populations to a "temporally-ordered" sequence of variability (Vannote and Sweeney 1980) to which fish populations have presumably adapted.

iii. Homing to natal streams promotes reproductive isolation in Pacific salmonids, and natural selective forces (including those imposed by NTR) operate on heritable phenotypic traits, resulting in distinct, *locally adapted* populations (Hillborn et al. 2003).

iv. Thus, dampening the natural thermal variability and the temporal sequence of the NTR reduces intraspecific diversity by reducing opportunities for local adaptation and genetic variation among populations or phenotypic variation within populations (Watters et al. 2003), and therefore, salmonid species diversity in Oregon.

v. Since diversity also confers stability in salmon population dynamics (production cycles), a diverse temperature regime also promotes population and meta-population (ESU) resilience. In addition, diversity in spawn timing among Pacific salmon and steelhead confers a stable food resource for other biota (Ruff et al. 2011).

f. Heat accumulation and other homogenizing effects may alter thermal heterogeneity well before changes to "average" main channel temperatures are detected (Poole and Berman 2001).

g. Thermal diversity promotes aquatic **biological productivity.**

i. If fish use temporal thermal diversity (migrating or foraging during cooler nighttime temperatures) or spatial thermal diversity (using cold-water refugia during mid-day) then impacts to the "pattern" of temperature could be as significant as changes to the mean or maximum temperature (DEQ 2003).

ii. It is not well understood how changes in temporal or spatial patterns of thermal diversity impact fish population dynamics, however it can be assumed that population dynamics are more closely linked to the dynamic spatial and temporal variability (diversity) of water temperatures and flows than to the mean of water temperatures.
iii. Fish can detect and exploit thermal heterogeneity to avoid heat stress, and meet metabolic and reproductive requirements (Berman and Quinn 1991, Hodgson and Quinn 1991, Torgersen et al. 2012).
iv. Under non-stressful temperature conditions juvenile coho that exploited thermal heterogeneity grew at substantially faster rates than did individuals that assumed other behaviors (Armstrong et al. 2013). This supports an emerging hypothesis that fish exploit thermal heterogeneity not only to survive, but thrive.
v. Variation in thermal regimes directly influence:
    1. Metabolic rates, physiology and life-history traits of aquatic ectotherms (see Holtby et al. 1989 for salmonid example) and
    2. Rates of important ecological processes such as nutrient cycling and productivity.
    3. It also indirectly mediates biotic interactions (references in Olden and Naiman 2010).
vi. Within a watershed stream network with multiple salmonid species, those with colder thermal requirements such as ESA-listed bull trout are almost completely confined to "cold-water refuges" in higher elevation headwater streams that are spatially isolated. If these refuges become warmer, bull trout habitat availability will shrink, due to competitive disadvantage with other salmonid species in the drainage network.
vii. Thermal refuges below the species-specific BBNC buffer cool/cold water adapted species from predation by invasive warm water predators.
viii. In warm streams, thermal refuge patches provide opportunities for fish to thermoregulate (Ebersole et al. 2003). Having a spatially distributed network of reaches and segments with cooler temperatures allows a fish population to utilize a larger portion of a stream network, thereby reducing density dependent and density independent mortality.

h. Multiple stressors in the environment must be considered. By preventing or reducing temperature stress, we reduce the risks due to multiple stressors on fish populations (see Baird & Burton 2001, US EPA 2001).
    i. Temperature increases, even below the numeric criteria, reduce the resistance of coho salmon to damaging effects of suspended sediment (Servizi & Martens 1991).
    ii. Feeding & growth rates of native & nonnative fish which feed on juvenile salmon increase as temperature increases (EPA 2001).

        iii. Cyprinid fish (e.g. redside shiners) are competitively favored over salmonids at warmer temperatures (EPA 2001).

    i. Water quality (particularly summer stream temperature) was identified in the Oregon Coastal Coho Assessment & Oregon Coastal Coho Conservation Plan as the secondary bottleneck for most coastal coho ESUs.

    j. Stream complexity contributes to thermal diversity.
        i. Cold groundwater (~7°C) influx & hyporheic exchange/conduction can account for apparent cooling downstream of harvest units (Story *et al* 2003). Cooling only occurred in gaining reaches.
        ii. Rather than cooling streams, hyporheic flows have a buffered temperature range (higher lows, lower highs) & are phase shifted (lagged) relative to the surface flow (water entering the hyporheic zone during the cool part of the day will likely exist during the warm part of the day & vice versa; Arrigoni *et al* 2008).
        iii. Hyporheic exchange is increased by stream complexity (Woessner 2000 & Dent *et al* 2001, cited in Story *et al* 2003 & Torgersen *et al* 2012).
        iv. Hydraulic effects of large woody debris (slowing & deflection of streamflows) create alluvial channels where there would otherwise be bedrock channels, increasing hyporheic & subsurface flow with attendant effects on temperature regimes (Montgomery *et al* 1996).
        v. Stream complexity (e.g. deflection & pool formation from boulders & large wood) increases the size & extent of cold water refugia by slowing mixing of cold water seeps with the main waterbody (Bilby 1984, cited in Torgersen *et al* 2012).

    k. When there is uncertainty, DEQ must make conservative choices to ensure protection of the resource.
        i. Uncertainty due to dynamics of the system (stochasticity).
        ii. Uncertainty due to our incomplete understanding of the system.
        iii. Uncertainty due to using sample data to observe the system.

3. Alleged that increases in temperature (at levels seen in RipStream) will diminish to less than 0.3°C within 300m on average. What can we say about downstream effects (in detail)?
    a. Physics of heat gain/loss.
        i. During summer, efficiency of heat loss is much lower than that of heat gain via solar radiation.
            1. In open canopy streams, input of solar radiation typically composes about 50% – 90% of the total heat energy flux (Johnson 2004, Benyahya *et al* 2012) & is the primary driver of heat transfer related to stream temperature change (Figures 1 & 2).
        ii. Added flow (increased mass of water) dilutes heat, but most heat remains in the system (e.g. Hannah *et al* 2008).
            1. Harder to detect the effects of a *single* source as water moves farther downstream.

2. Temperature is a measure of average thermal energy content, but DEQ also tracks thermal energy loads & fluxes (kcal) in TMDLs & other water quality programs.

iii. On small streams, DEQ HeatSource modeling indicates long distances (1000 meters +) are required to lose heat energy via evaporation and longwave radiation.

   1. The loss is slow because these fluxes are the primary processes for loss of heat, and they represent a small proportion of the total input from increased solar radiation (Figure 1).
   2. Tributary & groundwater mixing are held constant; only effects of vegetation change are modeled.

iv. DEQ HeatSource modeling indicates long distances (1000 meters +) are required to lose thermal energy via evaporation & longwave radiation (when flow is increased by x% to account for harvest-related flow increases).

   1. Surfleet & Skaugset (2013) found 45% increase in August flows with 13% of watershed harvested in 2005. When an additional 13% was harvested in 2009 (26% total), flows were 106% higher in the 1st year (2010) & 47% higher in the 2nd year (2011).
   2. Jones & Post (2004) looked at small PNW catchments with 100% harvest:
      a. ~50-100% increase in summer (June-Mid September) low flows 1-5 yrs post-harvest
      b. ~0-60% increase in summer low flows 6-10 yrs post-harvest
      c. ~30-50% deficits in summer low flows 24-35 yrs post-harvest

v. HeatSource modeling on 2 RipStream sites (5556 & 7854):

   1. Agrees well with field measured responses at the end of the harvest units;
   2. Shows persistent temperature increases a kilometer or more from the end of harvest units (Figures 3 & 4);
   3. Harvest of additional downstream unit on 5556 creates greater increase at confluence with Drift Creek (Figure 5).

b. Trask Study results?

   i. Preliminary results shown in Trask presumably showed privately harvested Type-N streams did not have readily detectable effects at downstream probe.
   ii. Small headwaters (small Type-N) streams often behave differently & have small flows compared to fish-bearing reaches.
      1. There is a great deal of change in heat capacity between harvest reaches & downstream sites, due to greater flows.
   iii. The format of data presented to the GNRO is difficult to understand—need more information to have an interpretation of this data.

            1. For example, does not appear to be harvest-related temperature changes on Type-N streams in harvest units. If true, wouldn't expect changes at downstream sites.
      iv. Between Type-N harvest units & downstream probe is a RipStream study site.
            1. During pre-harvest (2006-2011) period of Trask Study, RipStream site was in post-harvest condition (harvested in 2005, post-harvest year 1 was 2006).
            2. RipStream site had challenging-to-interpret temperature behavior. 2W (control) probe had post-harvest increases & there was not much harvest in the Riparian Management Area, so unable to see any effects at 3W (treatment) probe.
            3. Does this site confound interpretation of downstream effects from headwaters harvests?
   c. Cole & Newton (2013) showed that with uncut units interspersed with harvest units, stream reaches showed overall increases in temperature trends 2 or 5 years post-harvest for 3 of 4 study reaches.
   d. If taking a non-conservative approach to the effects of a single harvest, then we must address actual landscape conditions & the effects of multiple harvests.

4. Alleged that 2% of landscape in "early years" of rotation. What is the typical range, and what can we say about that?
   a. Two questions:
      i. How are the "early years" of the rotation being defined? It appears this figure may be % harvested per year on an even-flow 50-year rotation.
            1. An appropriate thermal recovery window is 7-15 years, given the literature on temperature/shade recovery (Johnson & Jones 2000; D'Souza *et al* 2011; Rex *et al* 2012; RipStream data, *unpublished*).
            2. Ten years is a reasonable mid-range timespan (See studies above; also Sherri Johnson, *personal communication*).
      ii. What spatial scale is being considered? How does ownership vary across space?
   b. Answers:
      i. 2% harvested per year on average for a 50 year rotation. Rotation length is more often 40 years, so 2.5% of the land harvested per year on average. For a 10 year temperature recovery timespan, 25% of industrial forestlands would be in thermal recovery.
      ii. There is high variation in percent ownership of forestlands (federal, state, municipal, private nonindustrial, private industrial) by sub-basin and basin and in harvest patterns.
      iii. The average percentage of private forestland (65.1% of total land area) in the MidCoast basin in the 10-yr thermal recovery period is 17% for the time period 1985-2009. The average for all land uses combined is 10%.
            1. An additional 5% did not have tree cover before 1985 & has not grown trees subsequently.

2. Varies over time & space.
    a. In 2008, 39.9% of private forestland in the Middle Siletz River watershed was in thermal recovery.
    b. In 1996, 5.3% of private forestland in the Drift Creek watershed was in thermal recovery. [34.9% in 2008]
3. Disturbance is calculated in rolling 10-yr intervals based on change in Landsat land cover from 1985-2009 (Figure 6).
4. Disturbance includes both harvest & fire.
5. Consistent with digitized harvest units area in ODF Vantage database (Kyle Abraham, *personal communication*)

iv. Based on change in Landsat land cover from 1985-2009, the average percentage of private forestland riparian areas in the MidCoast basin (43.8% of total riparian area (within 100ft of streams)) in the 10-yr thermal recovery period is 14.1% for the time period 1994-2009.
1. The average for private industrial forestland is 15.6% (36.2% of total riparian area) & for private nonindustrial forestland is 10.2% (7.6% of total riparian area).
2. The percentage of recently+chronically disturbed riparian areas is 20.7% for private forestlands during the same time period (20.4% & 21.8% for industrial & nonindustrial, respectively).
3. The average recent disturbance for riparian areas of all land uses collectively is 8.7%. The average chronic disturbance for riparian areas of all land uses collectively is 14.0%.
4. Varies over time & space.
    a. In 2008, 36.7% of private forestland riparian area in the Middle Siletz River watershed was in thermal recovery (maximum). The minimum of 14.1% occurred in 1994 (Figures 7 & 8).
    b. In 1996, 0.2% of private forestland riparian area in the Drift Creek watershed was in thermal recovery (minimum). The maximum of 25.8% occurred in 2008 (Figures 9 & 10).
    c. In 1999, 9.7% of private forestland riparian area in the Lake Creek watershed was in thermal recovery (minimum). The maximum of 34.5% occurred in 2008 (Figures 11 & 12).

v. In ODF's landslide study, (Robison *et al* 1999) 17% of study areas were in age class 0-9.

c. Prior to Euro-American settlement, fires created a heterogeneous (patchy) landscape with variable fire severity &varying intervals between fires.

i. Fire return intervals in western Oregon range from 100-400 years. Shorter intervals typically are associated with less severity (Morrison & Swanson 1990).

ii. Agee (1990) estimates that historically an average 0.24% and 0.67% of cedar/spruce/hemlock and Douglas-fir forests, respectively, burned annually.

        iii. Cedar/spruce/hemlock average per 10 years=2.4%; Douglas-fir average per 10 years=6.7%.

d. Wimberly (2002) estimates that a median of 17% of Oregon's coastal province would be in early successional condition (<30 years since fire).
    i. These fires are not all stand replacement but vary in severity.
    ii. Using 10 years as above, Wimberly's estimate gives 5.67% of forestlands historically in thermal recovery.
    iii. Swanson *et al* (2011) document the differences between natural early succession and clearcut harvest.

e. High-severity fires leave more wood & live vegetation than clearcut harvest (see Reeves *et al* 2006). Fire return for high severity fires is typically 200 years (Wimberly 2002), compared to harvest rotation of 40 years.

f. Periodic large scale disturbances create a mosaic of riparian & aquatic habitats (Bisson *et al* 2003). Pulses of sediment & large wood are delivered by post-fire erosion, in contrast to chronic inputs.
    i. Emphasize the importance of conserving & restoring processes, not merely creating a structure or a condition.
    ii. Managing for & like a natural disturbance.

g. Fire is less common in riparian areas (higher moisture content & humidity). They often have higher fuel loads (higher productivity) & in prolonged drought become more fire-prone. Riparian fires tend to be very patchy, primarily burning fine fuels. Some studies (e.g. Tollefson *et al* 2004, Olson & Agee 2005) have found no difference between upland & riparian fire frequency, particularly when riparian vegetation is similar to upland vegetation. Streams higher up in watersheds are more likely to burn along with upland forests. (Upper riparian forests: more fire disturbance; lower riparian forests: more flood disturbance.) Conditions retard fuel drying & decrease severity. Harvesting increases fuel loads & opens up canopy, allowing faster drying of fuels. Extent & spread complicated by heterogeneity. In very dry climatic conditions, riparian corridors can act a route fire spread (wind tunnel effect). More often, riparian areas make a natural fire break. Riparian vegetation diversity & adaptations & access to water lead to faster recovery (Reeves *et al* 2006, Pettit & Naiman 2007).

h. Olson & Agee (2005) found historic fire return intervals of 4-167 years for riparian areas & 2-110 years for upland area in the mixed-severity fire regime of the Umpqua basin (not significantly different). Fire was patchy & riparian areas had a greater range of return intervals than upland slopes.
    i. Drier end of Douglas-fir/western hemlock distribution.

i. Windthrow is a common riparian disturbance type that contributes large wood to streams & creates patches of different ages. Windthrow rates are significantly higher on buffered clearcut streams compared to partial cuts or controls; however, it is a minor contributor to overall sediment loads (Rashin *et al* 2006). Loss of trees would reduce shade.

j. Conifers are uncommon in many unmanaged Coast Range riparian areas. Hardwood dominance due to competition & small-scale disturbance is common (Nierenberg & Hibbs 2000).
k. Temperature 303(d) listings & TMDLs exist across Oregon's landscape.
l. If only 2-6% of landscape were in recently harvested (≤10yrs since harvest) condition at the 6th field scale, then there are significantly reduced risks of water quality impacts & fisheries impacts (see Thompson *et al* 2006 for information on historical disturbance as a reference for forest policy/harvest).

References:

Agee, James K. 1990. The historical role of fire in Pacific Northwest forests, p. 25-38. *In* Walstad, JD, SR Radosevich, and DV Sandberg (*eds.*) Natural and Prescribed Fire in Pacific Northwest Forests. Oregon State University Press, Corvallis, Oregon. 317pp.

Arrigoni, AS, GC Poole, LAK Mertes, SJ O'Daniel, WW Woessner, and SA Thomas. 2008. Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stream channels. Water Resources Research 44: W09418, doi:10.1029/2007WR006480.

Baird, DJ & GA Burton, Jr. (eds.) 2001. Ecological Variability: Separating Natural from Anthropogenic Causes of Impairment. Pensacola, Florida , USA: SETAC Press. 307pp.

Benyahya, L, D Caissie, MG Satish, and N El-Jabi. 2012. Lon-wave radiation and heat flux estimates within a small tributary in Catamaran Brook (New Brunswick, Canada). *Hydrological Processes* **26:** 475-484.

Bilby, RE. 1984. Characteristics and frequency of cool-water areas in a western Washington stream. *Journal of Freshwater Ecology* **2:** 593-602.

Bisson, PA, BE Rieman, C Luce, PF Hessberg, DC Lee, JS Kershner, GH Reeves, and RE Gresswell. 2003. Fir and aquatic ecosystems of the western USA: current knowledge and key questions. *Forest Ecology and Management* **178:** 213-229.

Cole, E, and M Newton. 2013. Influence of streamside buffers on stream temperature response following clear-cut harvesting in western Oregon. *Canadian Journal of Forest Research* **43:** 993-1005.

DeGroot, JD, SG Hinch, and JS Richardson. 2007. Effects of logging second-growth forests on headwater populations of coastal cutthroat trout: a 6-year, multistream, before-and-after field experiment. *Transactions of the American Fisheries Society* **136:** 211-226.

Dent, CL, NB Grimm, and SG Fisher. 2001. Multiscale effects of surface-subsurface exchange on stream water nutrient concentrations. Journal of the North American Benthological Society 20: 162-181.

DEQ. 2003. Summary of the Discussion and Findings of DEQ's Technical Advisory Committee on Water Quality Criteria for Temperature. http://www.deq.state.or.us/wq/standards/docs/temperature/TACsummaryTemp2003.pdf

D'Souza, L, M Reiter, LJ Six, & RE Bilby. 2011. Response of vegetation, shade and stream temperature to debris torrents in two western Oregon watersheds. *Forest Ecology and Management* **261:** 2157-2167.

Hannah, DM, IA Malcolm, C Souslby, and AF Youngson. 2008. A comparison of forest and moorland stream microclimate, heat exchanges and thermal dynamics. *Hydrological Processes* **22:** 919-940.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (Oncorhynchus kisutch). *Canadian Journal of Fisheries and Aquatic Sciences* **45**: 502-515.

INR (Institute for Natural Resources at Oregon State University). 2009. Managing for climate change in an ecosystem dynamics framework: Recommendations from April 16, 2009 seminar. *Dynamic Ecosystem Policy Project (Oregon Department of Forestry).* http://www.oregon.gov/odf/resource_planning/docs/inr_climate_change_white_paper.pdf

Johnson, Sherri L. 2004. Factors influencing stream temperatures on small streams: substrate effects and a shading experiment. *Canadian Journal of Fisheries and Aquatic Sciences* **61:** 913-923.

Johnson, SL, and JA Jones. 2000. Stream temperature response to forest harvest and debris flows in western Cascades, Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* **57(Suppl. 2):** 30-39.

Jones, JA, and DA Post. 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. *Water Resources Research* **40:** W05203, doi:10.1029/2003WR002952.

Kibler, KM, A Skaugset, LM Ganio, and MM Huso. 2013. Effect of contemporary forest harvesting practices on headwater stream temperatures: Initial response of the Hinkle Creek catchment, Pacific Northwest, USA. *Forest Ecology and Management* **310:** 680-691.

McCullough, DA. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. *United States Environmental Protection Agency Publication* EPA 910-R-99-010. 279pp.

Montgomery, DR, TB Abbe, JM Buffington, NP Peterson, KM Schmidt, and JD Stock. 1996. Distribution of bedrock and alluvial channels in forested mountain drainage basins. *Nature* **381:** 587-589.

Morrison, PH, and FJ Swanson. 1990. Fire history and pattern in a Cascade Range landscape. US Forest Service General Technical Report: PNW-GTR-254. 77pp.

Mote, Philip W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. *Northwest Science* **77:** 271-281.

Murphy, ML, C P Hawkins, and NL Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. *Trans. Am. Fish. Soc.* **110:** 469-478.

Nierenberg, TR, and DE Hibbs. 2000. A characterization of unmanaged riparian areas in the central Coast Range of western Oregon. *Forest Ecology and Management* **129:** 195-206.

Olson, DL, and JK Agee. 2005. Historical fires in Douglas-fir dominated riparian forests of the southern Cascades, Oregon. *Fire Ecology* **1:** 50-74.

Oregon Coastal Coho Conservation Plan. http://www.oregon.gov/OPSW/cohoproject/pdfs/november2007_pdfs/coho_plan.pdf

Pettit, NE, and RJ Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. *Ecosystems* **10:** 673-687.

Rashin, EB, CJ Clishe, AT Loch, and JM Bell. 2006. Effectiveness of timber harvest practices for controlling sediment related water quality impacts. *Journal of the American Water Resources Association* **42:** 1307-1327.

Reeves, GH, LE Benda, KM Burnett, PA Bisson, and JR Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. *American Fisheries Society Symposium* **17:** 334-349.

Reeves, GH, PA Bisson, BE Rieman, and LE Benda. 2006. Postfire logging in riparian areas. *Conservation Biology* **20:** 994-1004.

Rex, JF, DA Maloney, PN Krauskopf, PG Beaudry, and LJ Beaudry. 2012. Variable-retention riparian harvesting effects on riparian air and water temperature of sub-boreal headwater streams in British Columbia. *Forest Ecology and Management* **269:** 259-270.

Robison, E.G., K. Mills, J. Paul, L. Dent, and A. Skaugset. 1999. Oregon Department of Forestry Storm Impacts and Landslides of 1996: Final Report. Forest Practices Technical Report No. 4. Oregon Department of Forestry, Salem, Oregon.

Ruesch, AS, CE Torgersen, JJ Lawler, JD Olden, EE Peterson, CJ Volk, and DJ Lawrence. 2012. Projected climate-induced habitat loss for salmonids in the John Day River network, Oregon, U.S.A. *Conservation Biology* **26:** 873-882.

Servizi, JA, and DW Martens. 1991. Effect of temperature, season, and fish size on acute lethality of suspended sediments to coho salmon (*Oncorhynchus kisutch*). *Can J Fish Aquat Sci* **48:** 493-497.

Story, A, ED Moore, and JS Macdonald. 2003. Stream temperatures in two shaded reachesbelow cutblocks and logging roads: downstream cooling linked to subsurface hydrology. *Canadian Journal of Forest Research* **33:** 1383-1396.

Surfleet, CG, and AE Skaugset. 2013. The effect of timber harvest on summer low flows, Hinkle Creek, Oregon. *Western Journal of Applied Forestry* **28:** 13-21.

Swanson, ME, JF Franklin, RL Beschta, CM Crisafulli, DA DellaSala, RL Hutto, DB Lindenmayer, and FJ Swanson. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Frontiers in Ecology and the Environment* **9:** 117-125.

Thompson, JR, KN Johnson, M Lennette, TA Spies, and P Bettinger. 2006. Historical disturbance regimes as a reference for forest policy in a multiowner province: a simulation experiment. *Canadian Journal of Forestry Research* **36:** 401-417.

Tollefson, JE, FJ Swanson, and JH Cissel. 2004. Fire severity in intermittent drainages, Western Cascade Range, Oregon. *Northwest Science* **78:** 186-191.

Torgersen, CE, JL Ebersole, and DM Keenan. 2012. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. *United States Environmental Protection Agency Publication* EPA 910-C-12-001. 78pp.

Trotter, P. C. 1989. Coastal Cutthroat Trout: A Life History Compendium. *Trans. Am. Fish. Soc.* **118:** 463-473.

US EPA, Region 10. 2001. Temperature Project Technical Issue Papers. http://yosemite.epa.gov/r10/water.nsf/6cb1a1df2c49e4968825688200712cb7/5eb9e547ee9e111f88256a03005bd665!OpenDocument

Welsh, HH, GR Hodgson, and BC Harvey. 2001. Distribution of juvenile coho salmon in relation to water temperatures in tributaries of the Mattole River, California. *North American Journal of Fisheries Management* **21:** 464-470.

Wigington, PJ Jr., and others. 2006. Coho salmon dependence on intermittent streams. *Frontiers in Ecology and the Environment* **4:** 513-518.

Woessner, WW. 2000. Stream and fluvial plain ground water interactions: rescaling hydrogeologic thought. *Ground Water* **38:** 423-429.

Wimberly, MC. 2002. Spatial simulation of historical landscape patterns in coastal forests of the Pacific Northwest. *Canadian Journal of Forest Research* **32:** 1316-1328.